Journal of King Saud University – Engineering Sciences (2015) 27, 170–175

King Saud University

Journal of King Saud University – Engineering Sciences

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SHORT COMMUNICATION

# Enhancement of distillate output of double basin solar still with vacuum tubes

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Received 19 March 2013; accepted 15 June 2013
Available online 24 June 2013

**KEYWORDS**

Double basin solar still;
Distillate output;
Black granite gravel

**Abstract** In this research paper, attempts are made to make a double basin solar still. The overall size of the lower basin used is 1006 mm × 325 mm × 380 mm and the outer basin is 1006 mm × 536 mm × 100 mm. Black granite gravel is used to increase the distillate output by reducing the quantity of brackish or saline water in both basins. Several experiments have been conducted to determine the performance of a solar still in climate conditions of Mehsana (latitude of 23°59′ and longitude of 72° 38′), Gujarat. Here, three conditions used to determine the performance of double basin solar still like a double basin solar still alone, double basin solar still with black granite gravel, double basin solar still with vacuum tubes and double basin solar still with vacuum tubes and black granite gravel. Experimental results and comparison with other researchers show that, the daily distillate output increases by coupling vacuum tubes and by coupling vacuum tubes and black granite gravel to 56% and 65% respectively.



## 1. Introduction

Water is essential for all life forms on earth-plants, animals and human being, etc. For fresh water requirements humanity is dependent on rivers, ponds, lakes and underground water reservoirs. The available fresh water on earth is fixed, but the demand of fresh water is increased due to population growth and rapid industrialization. Industrial wastes and sewage discharges are mostly mixed in the rivers, so the available fresh water availability is reduced. The provision of fresh water is gradually becoming a more important issue in many areas of the world. Oceans are the only available source of large amount of water and since they contain high levels of salt, desalination of the water is necessary. Desalination is one of humankind's most primitive forms of water treatment and it is still a popular treatment solution throughout the world today. In natural desalination process solar radiation is absorbed by the sea and causes water to evaporate. The evaporated water rises above the earth's surface and moved by the wind. Once this vapour cools down to its dew point temperature, condensation occurs and the fresh water comes down as rain. The basic process is responsible for the hydrological cycle. This same principle is used in all man-made distillation systems using alternate sources of heating and cooling.

Solar still is a device, which is used for desalination purpose. Solar still is of two types namely passive solar still and

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Peer review under responsibility of King Saud University.

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http://dx.doi.org/10.1016/j.jksues.2013.06.007

active solar still. Generally, passive solar still employs only solar radiation to evaporate water for the production of distillate output, whereas, active solar still requires the addition of some mechanical source in the form of collector with solar energy. Hence, efficiency as well as distillate output of active solar still is good compared with passive solar still. Most of researchers, who worked on active solar still, used flat plate collector or concentrating collector with a single slope solar still. Rai and Tiwari (1983) have proved that, solar still coupled with flat plate collector increases distillate output of 24% compared with single slope single basin solar still. Tiris et al. (1998) found that coupling of flat plate collector with a solar still produces distillate output of 5 l compared with the output of 3 l from single slope solar basin solar still. Badran and Al–Tahainesh (2005) proved that, flat plate collector coupled with solar still increased efficiency of 35% compared with single slope single basin solar still in Iranian climate conditions. Dimri et al. (2008) found that, coupling a flat plate collector with higher thermal conductivity material produces higher distillate output as well as efficiency compared with single slope solar still. Voropoulus et al. (2001) connected solar pond with solar collector and solar still. They proved that coupling a solar collector and solar pond produces double productivity than passive solar still. Panchal et al. (2011) made an experiment with solar still with a flat plate collector in climate conditions of Mehsana, Gujarat. They proved 29% increase in the efficiency of solar still by coupling of flat plate. Abdel-Rahim and Lasheen (1981) made a modified design of solar still with parabolic trough focal pipe heat collector with solar still. They proved 18% increase in the efficiency of solar still. Panchal et al. (2011) made an experiment with evacuated glass tube collector with solar still in climate conditions of Mehsana, Gujarat. They found 40% increase in distillate output of solar still. Sampathkumar Karuppusamy (2012) proved that, coupling an evacuated glass tube collector with solar still increases the efficiency to 49.7%. Kargar Sharif Abad et al. (2013) integrated pulsating heat pipe with solar still. They found a remarkable increase in the rate of desalinated water production with the maximum production of 875 mL/m$^2$h.

The main objective of this work is to investigate experimental performance of the double basin solar with vacuum tubes. To increase distillate output of a solar still, black granite gravel is used inside the inner and outer basins of a solar still to reduce the quantity of water.

## 2. Procedure of experiment

Solar radiation is transmitted through toughened glass cover to the saline or brackish water in the basin. Thus, basin water gets heated and evaporated. Evaporated water particles condense on the inner side of the glass cover. The condensed water flows down the cover due to slope and reaches the distillate channel, where it collected by the flask. At the beginning of an experiment, the water level inside both basins is maintained at 4 cm. The experiment is commenced after 9 h, starting from morning 9 am to evening 5 pm with assuming steady state conditions built at every hour. Here, these hours are selected because of bright sunshine occurs during such hours. For each experiment, glass cover is cleaned to avoid dust collection on the top of glass cover of the outer basin solar still. Here, experiments have been conducted in the sunny days of March, 2012. Variables measured in the present experiments are water temperature of the outer basin (Tw1), inner glass cover temperature of the outer basin (Tgi1), water temperature of the inner basin (Tw2), inner glass cover temperature of the inner basin (Tgi2), Ambient Temperature (Ta), vacuum tube inlet temperature (Tbi), vacuum tubes outlet temperature (Tbo), solar radiation on evacuating tubes (I (t) e), solar radiation with glass cover (I (t) g) wind speed (V) and distillate output. Here, all

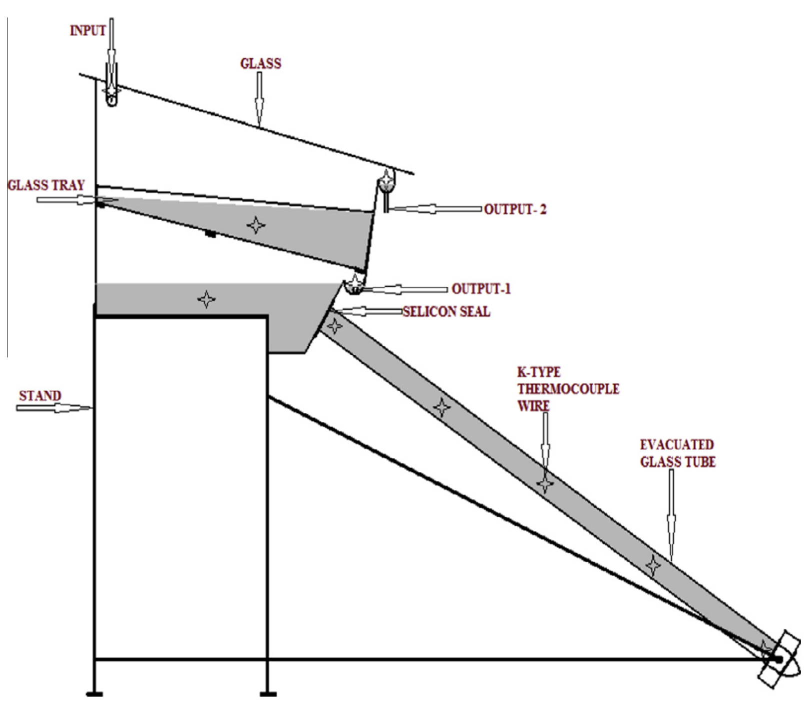


**Figure 1** Experimental set up of solar still coupled with vacuum tubes.

**Figure 2** Pictorial view of double basin solar still with vacuum tubes.

the experiments were conducted during sunshine hours only. Hence, cloudy condition days are not preferred in the present experiment. Average velocity of wind is 2–3 m/s.

### 3. Experimental set up

Experimental setup is installed at Gitanjali Society, Mehsana (latitude of 23°59′ and longitude of 72° 38′) Gujarat, India. Mehsana is a city, which is having more than 250 day's sunshine in a year. It is a city, where average solar insolation is of 800 watt/$m^2$. Hence, Mehsana is the best location of solar energy experiments and chosen for this experiment. Major elements required for experimental set up are double basin solar still and vacuum tubes. Experimental set up is as shown in Fig. 1. Pictorial view of the double basin solar still with vacuum tubes is shown in Fig. 2. The overall size of the inner basin used is 1006 mm × 325 mm × 380 mm, and outer basin is 1006 mm × 536 mm × 100 mm. Absorber plates used in inner basin and outer basin are made of aluminium sheet with black chrome paint for increasing absorptivity of solar radiation. An insulation of 4 cm thickness is provided at the bottom and sides of the outer basin to prevent heat losses. Here PUF (polyurethane foam) with thermal conductivity of 0.025 W/m2 K is used for the present experiment. Evaporated water inside inner and outer basins is condensed by toughened glasses of 3 cm thickness. Condensed water of the inner basin and outer basin is collected by hanging jars. Here, hanging jar is denoted by output 1 and output 2 of Fig. 1. A silicone rubber sealant is provided to hold toughened glass in contact with solar still surfaces. Total 4 holes are made on the inner basin and outer basin for the location of thermocouples. Here, 14 vacuum tubes are coupled with making a 6 cm diameter hole in the lower side of the inner basin. Vacuum tubes are connected to still stand at an angle of 35° with respect to the horizontal axis. Rubber gaskets are provided to fix vacuum tubes attached to the inner basin of a solar still. Bottom portion of vacuum tubes is connected to a sponge material to prevent breakage of vacuum tubes. Fig. 3 shows detailed drawing of double stage solar still. Instruments used in the present experiment with their accuracy, range and percentage of error are shown in Table 1. Fig. 5 shows that there is increase of 56% distillate output of solar still by adding vacuum tubes at lower basin of solar still.

### 4. Result and discussion

To increase distillate output of the double basin solar still, vacuum tubes were directly coupled with an inner basin of a solar still. To increase distillate output, apart from attaching vacuum tubes, black granite gravel was also used to reduce the quantity of water inside inner and outer basins and also increase in area. Black granite gravel possesses a very good characteristic of not only working as an energy storage medium but also as a medium which releases energy during off sunshine hours. Hence, introduction of black granite gravel with vacuum tubes produced considerable distillate output compared with other experimental techniques used by various researchers.

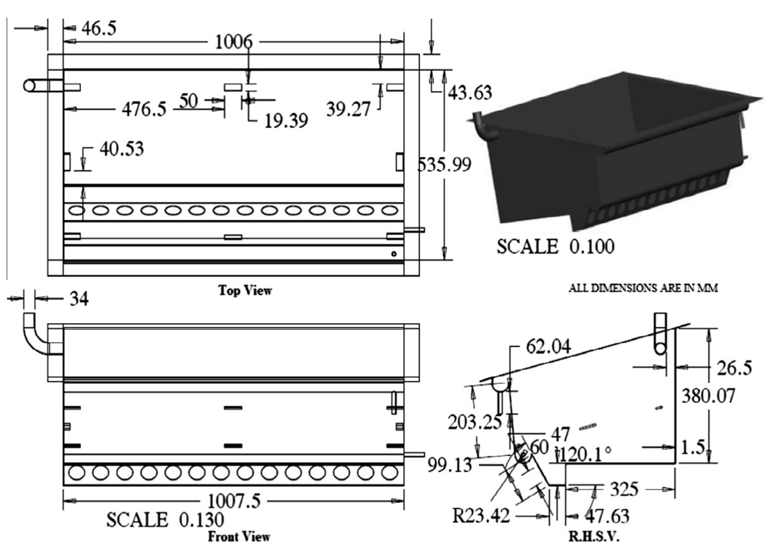


**Figure 3** Detailed drawing of double basin solar still chamber.

**Table 1** Instruments' name with their accuracy, range and percentage of error [14].

| Sr. No. | Instrument | Accuracy | Range | % error |
|---|---|---|---|---|
| 1 | Thermometer | ± 1 °C | 0–100 °C | 0.25 |
| 2 | Copper Constantan Thermocouple | ± 0.1 °C | 0–100 °C | 0.5 |
| 3 | Solarimeter | ± 1 W/m$^2$ | 0–2500 W/m$^2$ | 2.5 |
| 4 | Anemometer | ± 0.1 m/s | 0–15 m/s | 10 |
| 5 | Measuring Jar | ± 10 ml | 0–1000 ml | 10 |

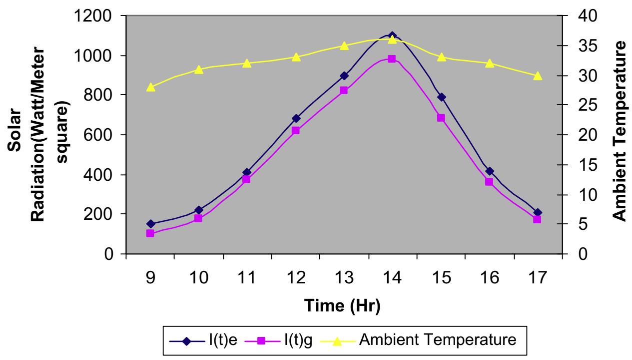


**Figure 4** Variation of ambient temperature and solar radiation.

*4.1. Effect of ambient temperature and solar radiation on double basin solar still*

Solar still distillate output depends on climate conditions of the place like solar radiation, ambient temperature etc. Fig. 4 shows variation of solar radiation and ambient temperature on 5/4/2012. The solar radiation gradually increases from early morning to 2 pm due to bright sunshine and then reduced towards evening due to low sunshine. It reaches maximum value of 1100 W/m$^2$. The ambient temperature was as its minimum 28 °C during 9 am and it reached the maximum value of 36° during 2 pm. The above parameters are purely based on climate conditions of the particular day. Fig. 4 shows effect of coupling vacuum tubes with solar still.

*4.2. Effect of coupling of vacuum tube collector to lower basin of solar still*

Basin water temperature as well as the inner glass cover is the best parameter to get enhanced distillate output from solar still. The vacuum tube experimental setup is installed at Gitanjali Society, Mehsana (latitude of 23°59′ and longitude of 72° 38′) Gujarat, India. Mehsana is a city, which is having more than 250 day's sunshine in a year. It is a city, where average solar insolation is of 800 watt/m$^2$. Hence, Mehsana is the best location of solar energy experiments and chosen for this experiment. Major elements required for experimental set up are double basin solar still and vacuum tubes. Experimental set up is as shown in Fig. 1. Pictorial view of the double basin solar still with vacuum tubes is shown in Fig. 2. The overall size of the inner basin used is 1006 mm × 325 mm × 380 mm, and outer basin is 1006 mm × 536 mm × 100 mm. Absorber plates used in the inner basin and outer basin are made of aluminium sheet with black chrome paint for increasing absorptivity of solar radiation. An insulation of 4 cm thickness is provided at the bottom and sides of the outer basin to prevent heat losses. Here PUF (polyurethane foam) with thermal conductivity of 0.025 W/m$^2$ K is used for the present experiment. Evaporated water inside inner and outer basins is condensed by toughened glasses of 3 cm thickness. Condensed water of inner basin and outer basins is collected by hanging jars. Here, hanging jar is denoted by output 1 and output 2 of Fig. 1. A silicone rubber sealant is provided to hold toughened glass in contact with solar still surfaces. Total 4 holes are made on the inner basin and outer basin for the location of thermocouples. Here, 14 vacuum tubes are coupled with making a 6 cm diameter hole in the lower side of the inner basin. Vacuum tubes are connected to still stand at an angle of 35° with respect to the horizontal axis. Rubber gaskets are provided to fix vacuum tubes attached to the inner basin of a solar still. Bottom portion of vacuum tubes is connected to a sponge material to prevent breakage of vacuum tubes. Fig. 3 shows detailed drawing of double stage solar still. Instruments used in the present experiment with their accuracy, range and percentage of error are shown in Table 1.

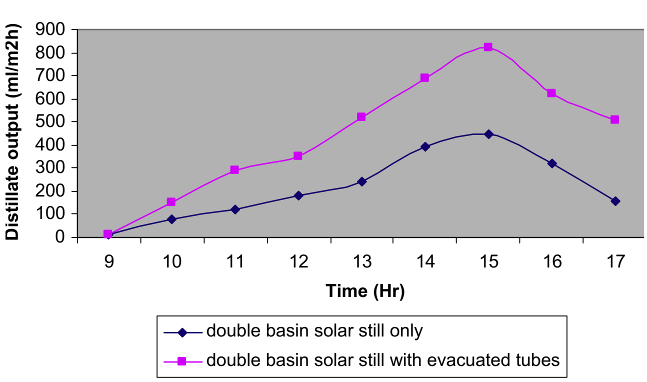


**Figure 5** Effect of coupling vacuum tubes on double basin solar still distillate output.

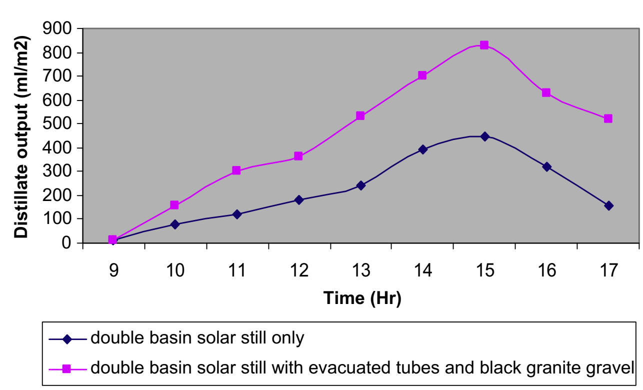


**Figure 6** Effect of coupling vacuum tubes and black granite gravel on double basin solar still.

**Table 2** Percentage increase in distillate output for various active methods for solar still.

| Sr. No. | Name of Researcher | Type of active method of solar still | Increase in distillate output (%) |
|---|---|---|---|
| 1 | Hitesh N. panchal (2011) [8] | Flat plate collector | 29 |
| 2 | S.N. Rai et.al. [2] | Flat plate collector | 24 |
| 3 | O.O. Badran et.al. [4] | Flat plate collector | 36 |
| 4 | Hitesh N. Panchal et.al. [10] | Evacuated tube collector | 40 |
| 5 | Zeinab S. Abdel-Rehim et.al. [9] | Parabolic collector | 18 |
| 6 | Sampathkumar Karuppusamy [11] | Evacuated tubes | 49.7 |
| 7 | Present work | Evacuated tubes | 56 |

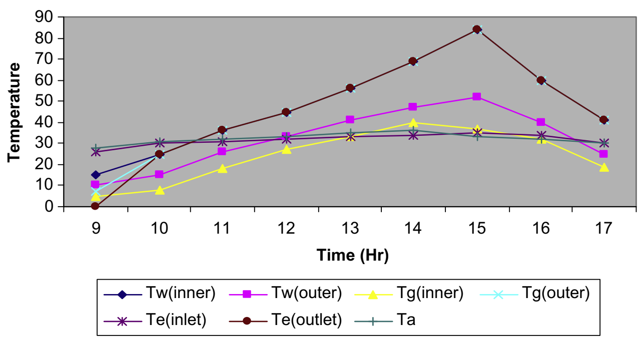


**Figure 7** Hourly variations of temperatures recorded in double basin solar still.

### *4.3. Effect of black granite gravel on distillate output of solar still*

Black granite gravel was used mainly in the solar still to reduce the quantity of water inside the basin. There is a considerable distillate output obtained by the introduction of black granite gravel coupled with vacuum tubes. Panchal et al. (2011) Proved that, less quantity of water inside the basin, increases distillate output of a solar still, hence productivity is increased by reducing the quantity of water and maintaining at the same level throughout the experiment. In this present experiment, black granite gravel is acting as an energy storage medium and during evaporation it also increases capillary action, hence the distillate output is increased by use of it. Effects of black granite gravel on double basin solar still and double basin solar still with black granite gravel and vacuum tubes are shown in Fig. 6. The daily average distillate output has increased by 9% while using black granite gravel in a double basin solar still and by 65% with the introduction of black granite gravel with vacuum tubes in a double basin solar still. Fig. 7 shows hourly variations of temperatures recorded by thermocouples at various locations of double basin solar still.

Various active methods applied to solar still to increase distillate output like flat plate collector, parabolic trough collector used by various researchers and the present research (double stage solar still with vacuum tubes) are shown in Table 2 in terms of increase in distillate output.

## 5. Economic analysis

Payback period of the double basin solar still coupled with evacuated tubes depends on various costs like fabrication cost. Operating cost, maintenance cost, feed water cost and financial subsidy are offered by the Government. Table 3 shows economic analysis of solar still.

## 6. Conclusion

In this present work, double basin solar still coupled with evacuated tubes was fabricated and tested in climate conditions of Mehsana, Gujarat. Many experiments have been conducted to enhance distillate output of solar still. The performance of alone double basin solar still was compared with that of still coupled with evacuated tubes with and without black granite gravel. It was found that, distillate output is increased to 56% with adding vacuum tubes and 65% of adding vacuum tubes and black granite gravel in double basin solar still. Due to low cost, simplicity, easy handling, and high distillate output, vacuum tubes proved to be another viable option for high temperature distillation option compared with flat plate collectors, which were used by various researchers. Annual yield of vacuum tubes will be more compared with flat plate collector as well as parabolic collector. Economic analysis showed payback period of 195 days.

**Table 3** Economic analysis of solar still.

| Sr. No. | Particular | Cost in INR |
|---|---|---|
| 1 | Fabrication cost | 9151 Rs. ($ 194.70) |
| 2 | Operating cost | 5 Rs./day ($ 0.1) |
| 3 | Maintenance cost | 5Rs./day ($ 0.1) |
| 4 | Cost of feed water | 1Rs/day ($ 0.02) |
| 5 | Cost of distilled water | 12 Rs/L ($ 0.26) |
| 6 | Cost of water produced/day | Rs. 60 |
| 7 | Subsidized cost given by government | 4% = 366.28 ($ 7.80) |
| 8 | Net profit = cost of water produced-operating cost-maintenance cost-cost of feed water | Rs. 45 ($ 0.95) |
| 9 | Payback period | 8785/45 = 195 days |

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